Charm Mixing in FOCUS

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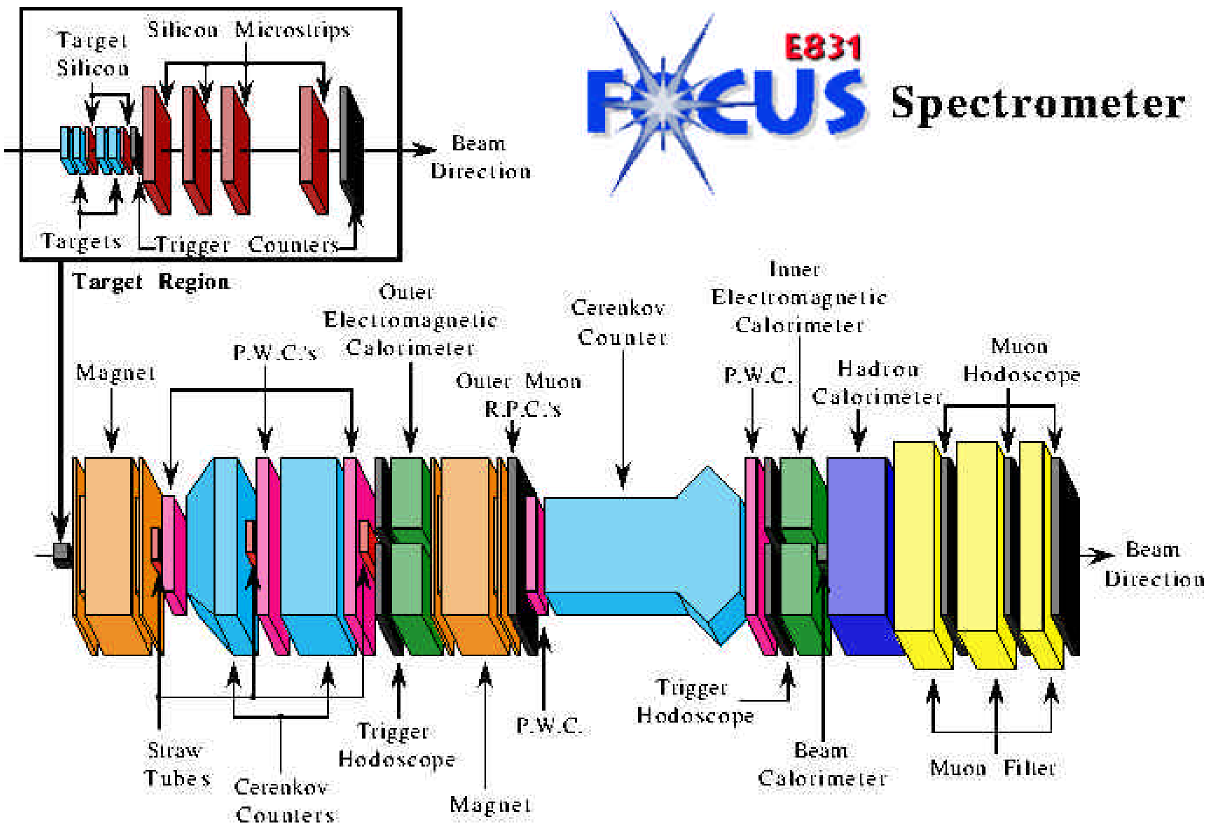
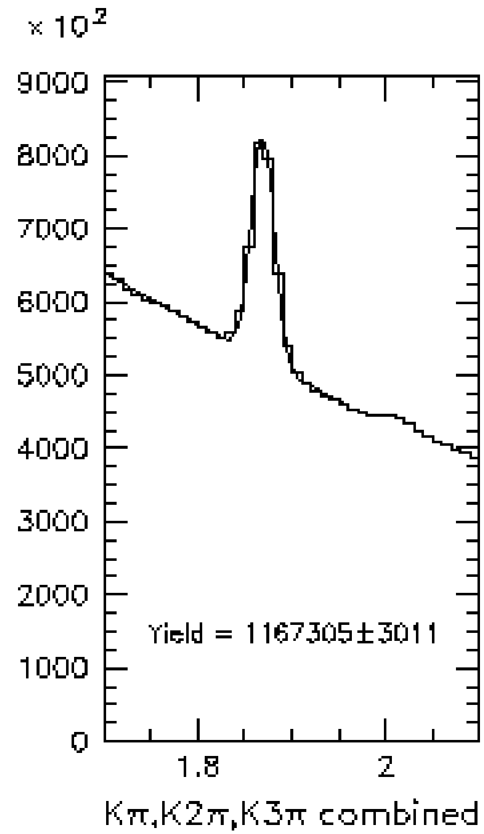
FOCUS is a Charm Photoproduction Experiment at Fermilab





This design facilitates excellent vertex resolution, particle identification and momentum resolution.

More than 1 million fully reconstructed *D* mesons!

Collaborating Institutions

University of California, Davis

CBPF (Brazil)

CINVESTAV (Mexico)

University of Colorado, Boulder

Fermi National Accelerator Laboratory

Laboratori Nazionali di Frascati dell'INFN (Italy)

University of Illinois, Urbana

Indiana University, Bloomington

Korea University, Seoul

INFN and University of Milano (Italy)

University of North Carolina, Asheville

INFN and University of Pavia (Italy)

University of Puerto Rico, Mayaguez

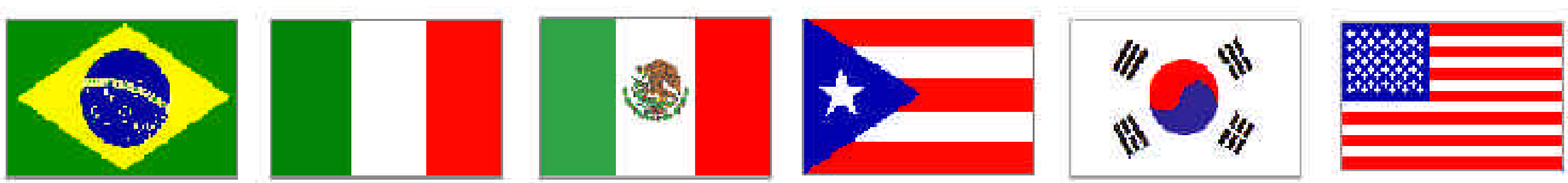
University of South Carolina, Columbia

University of Tennessee, Knoxville

Vanderbilt University (Nashville, TN)

University of Wisconsin, Madison

~ 100 Physicists



Study of D^0 Lifetime Differences

(PLB 495, 62)

Look for a lifetime difference between CP even and CP odd eigenstates states.

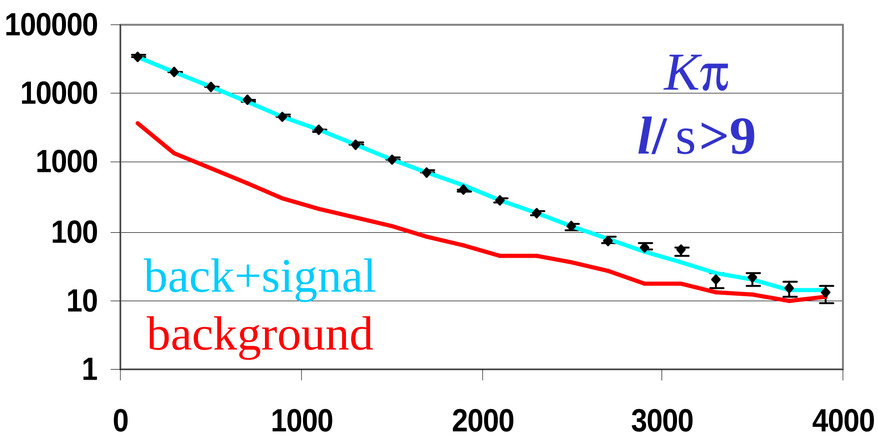
$$y = \frac{\Delta\Gamma}{2\Gamma} = \frac{\Gamma_{\text{even}} - \Gamma_{\text{odd}}}{\Gamma_{\text{even}} + \Gamma_{\text{odd}}}$$

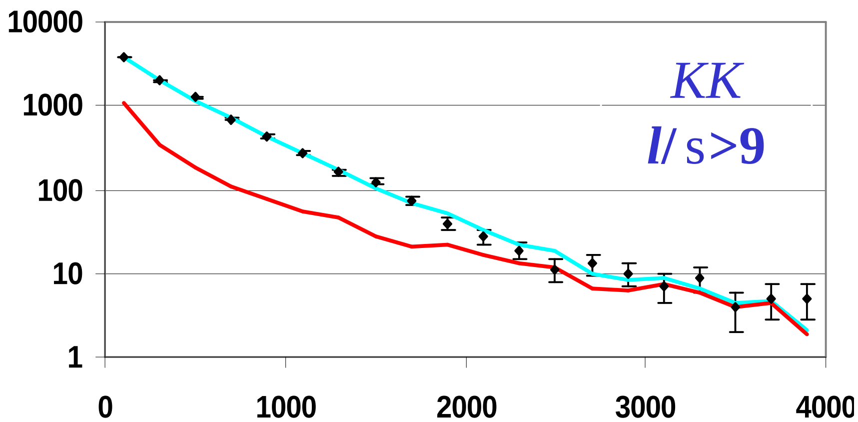
The final state K^+K^- is pure CP even and $K^-\pi^+$ is mixed CP (we assume it is an even mixture) then:

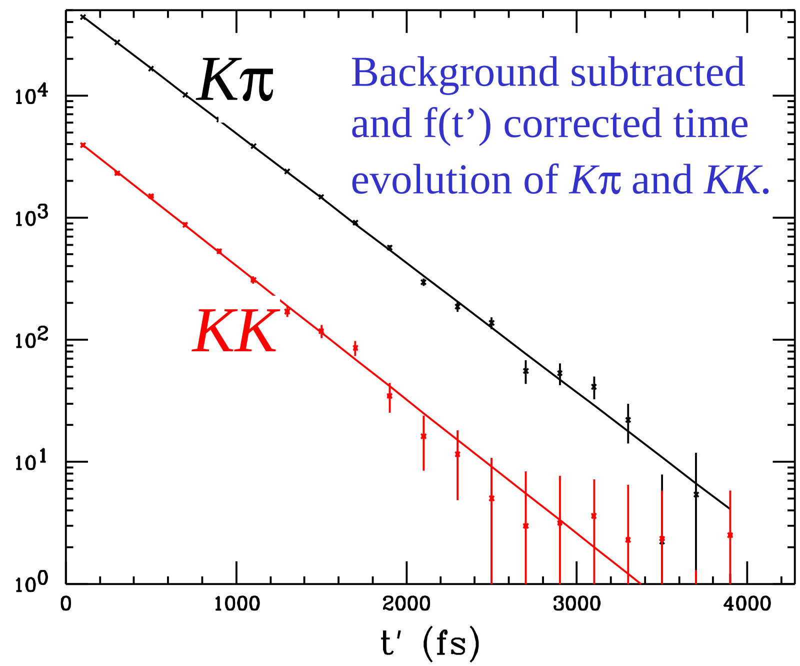
$$y = \frac{\Gamma_{\text{even}} - \Gamma_{\text{odd}}}{\Gamma_{\text{even}} + \Gamma_{\text{odd}}} = \frac{t(D^0 \rightarrow K^- \mathrm{p}^+)}{t(D^0 \rightarrow K^- K^+)} - 1$$

Fitted: Time evolutions

Before background subtraction







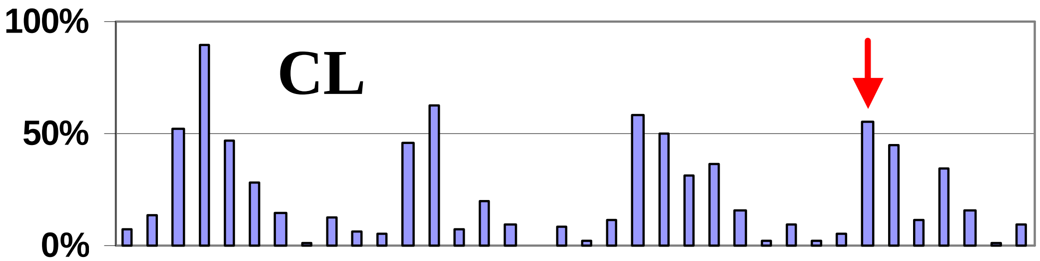
$$\tau(K\pi) = 409.2 \pm 1.3 \; fs$$

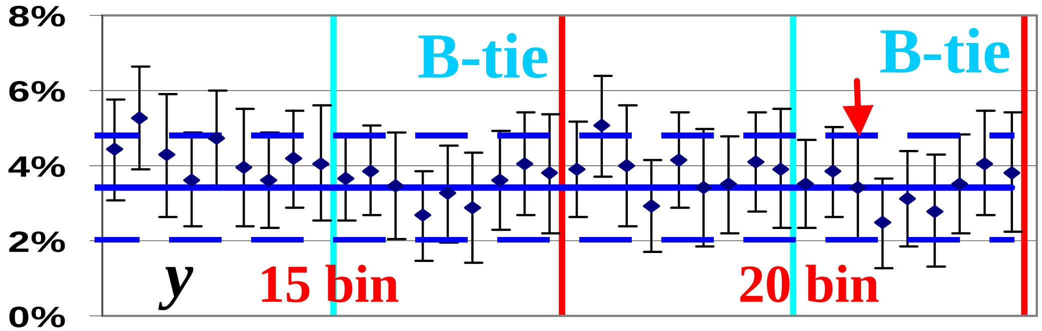
$$\tau(KK) = 395.7 \pm 5.5 \; fs$$

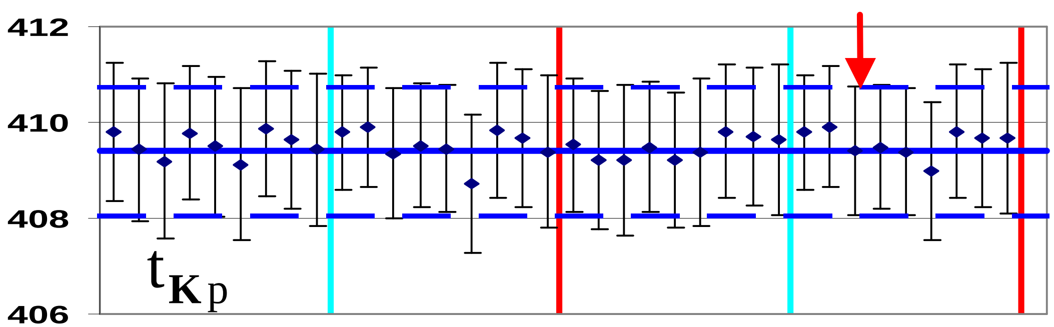
and

$$y = (3.42 \pm 1.39 \pm 0.74)\%$$

y Systematic Studies







3 K id $\times$ 3 l/s $\times$ B-tie or not $\times$ 15/20 bin = 36 fit variants shown.

y = 3.42±1.39±0.74 %

Sample standard deviation of fit variants is **±0.63**.

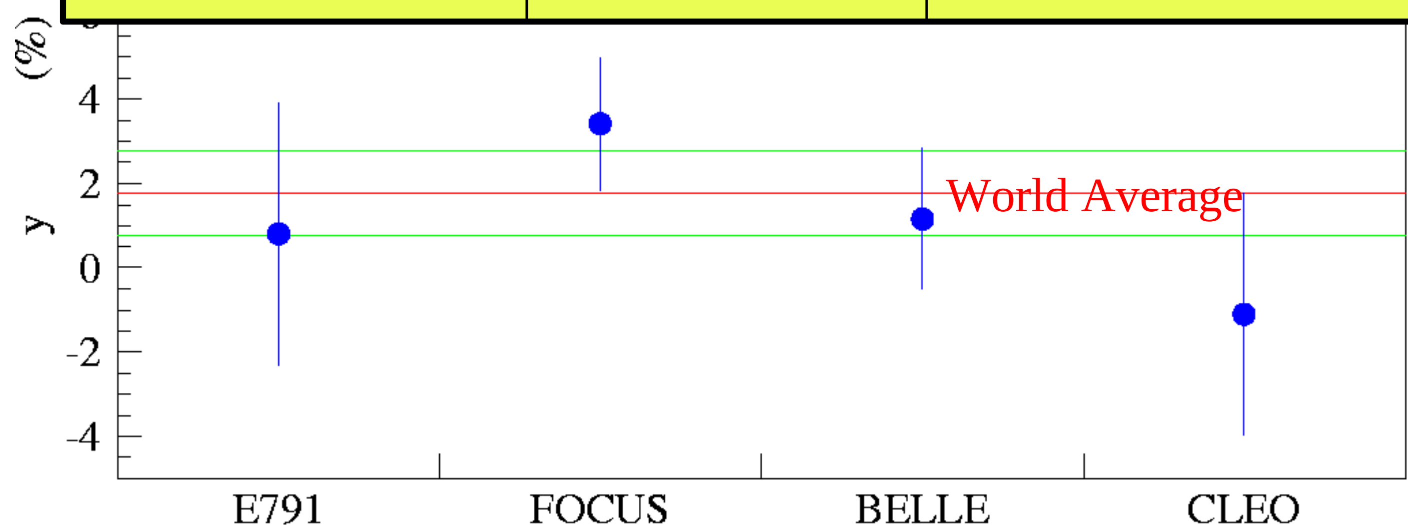
$\tau(K\pi)$ = 409.2±1.3±?? fs

Sample standard deviation of fit variants **±0.3.**

Absolute lifetime systematics not ready until we analyze $K3\pi$, etc.

Comparison of *y* Results

Experiment	y (%)	Lifetime D^0? Kπ (fs)
E791	$0.8 \pm 2.9 \pm 1.0$	$413 \pm 3 \pm 4$
FOCUS	$3.42 \pm 1.39 \pm 0.74$	409.2 ± 1.3 (Stat. Only)
BELLE (Preliminary)	$1.16^{+1.67}_{-1.65}$	414.5 ± 1.7 (Stat. Only)
CLEO (Preliminary)	$-1.1 \pm 2.5 \pm 1.4$	404.6 ± 3.6 (Stat. Only)
World Average	1.77 ± 1.00	412.6 ± 2.8 (PDG 2K)



Study of the Decay D^0? $K^+\pi^-$

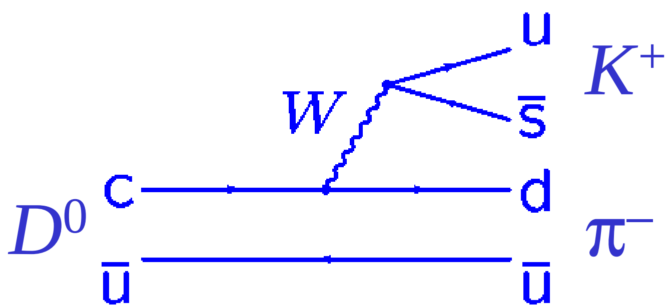
(hep-ex/0012048 to be published in PRL)

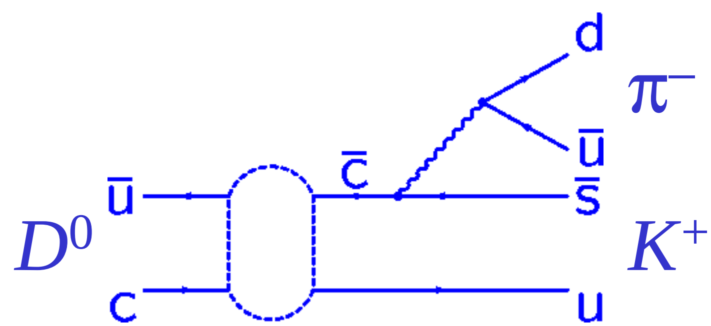
D^0 **g** $K^+\pi^-$ may occur through two processes:

Doubly Cabibbo Suppressed (DCS)

or

Mixing
Followed by a Cabibbo Favored Decay (CF)





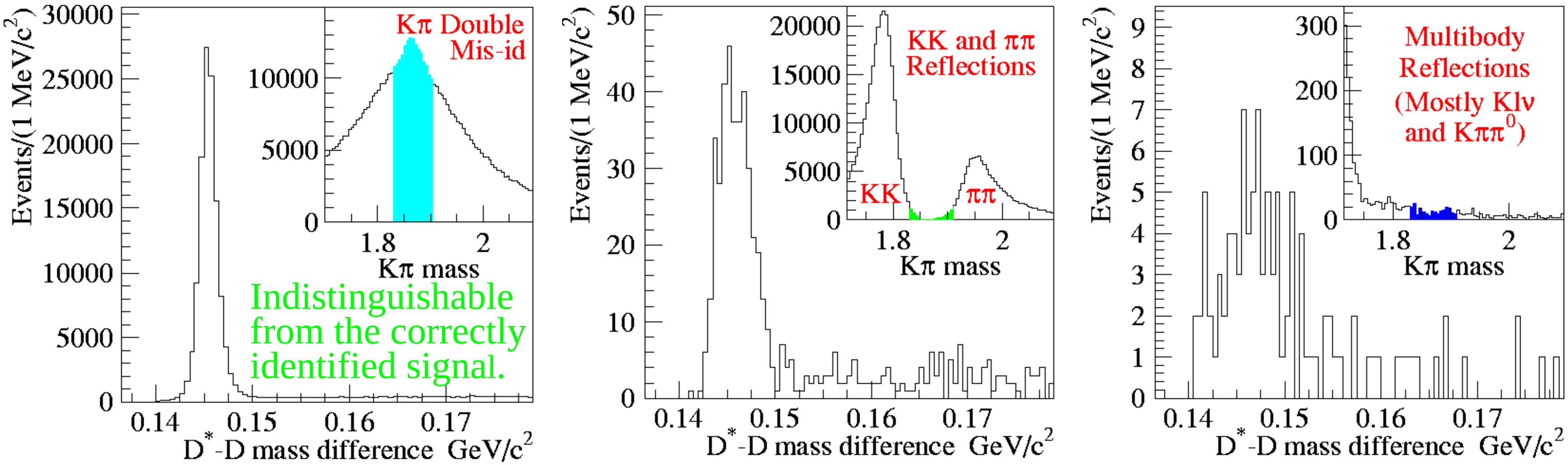
Standard Model predictions for contributions to the relative branching ratio.

$\tan^4\theta_C = 0.25\%$

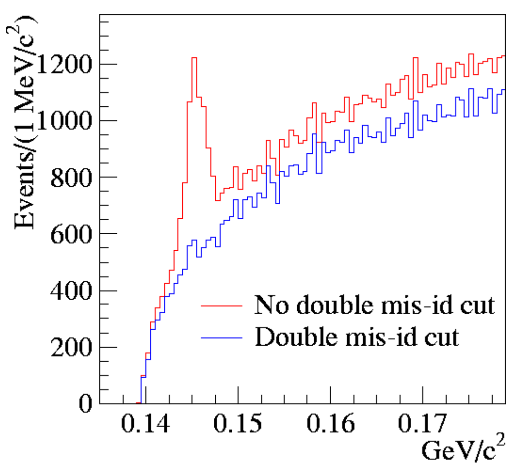
10^{-8} to 10^{-3}

Monte Carlo Background Studies

Backgrounds from other D^0 decays peak in the D^* signal region!



If not dealt with these backgrounds could seriously bias the analysis.

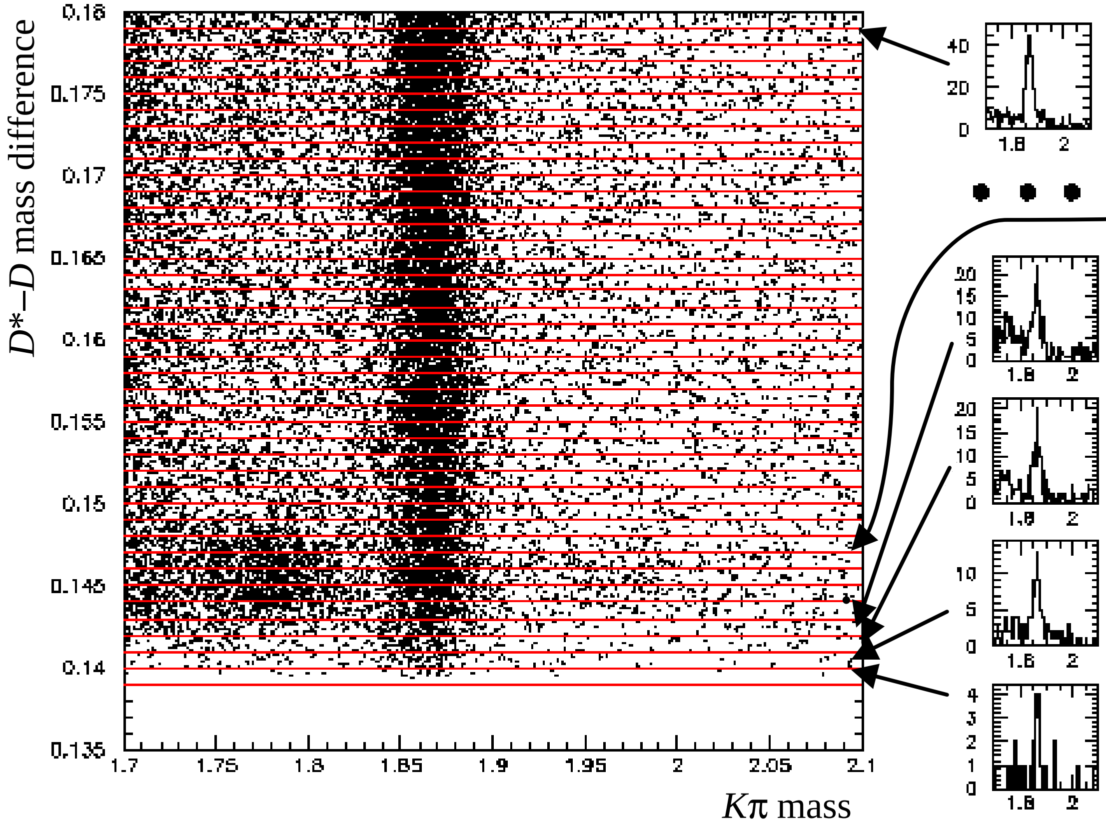


To Deal With Double Mis-id

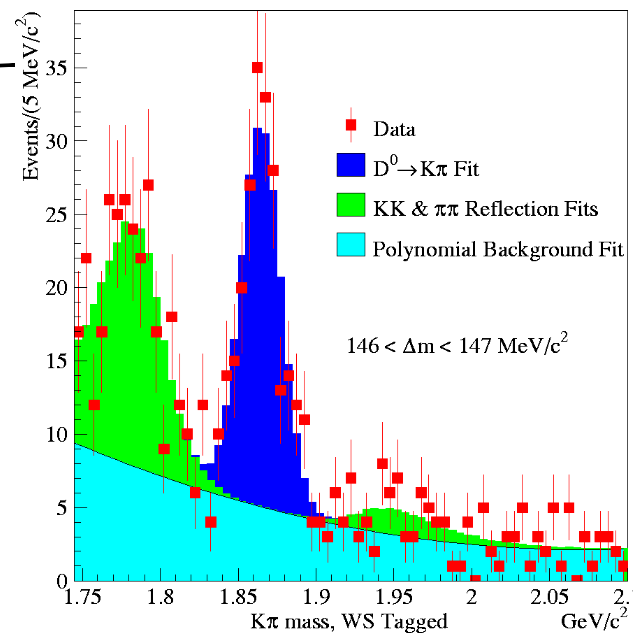
We use a tight Cerenkov id cut in an 8σ window about the D^0 mass with $K\pi$ reconstructed as πK.

A New Background Suppressing Fit Method

- Divide the data into 1 MeV wide bins in Δm, and fit the D^0 in each bin.
- Fit the *KK* and $\pi\pi$ reflections to Monte Carlo line shapes.



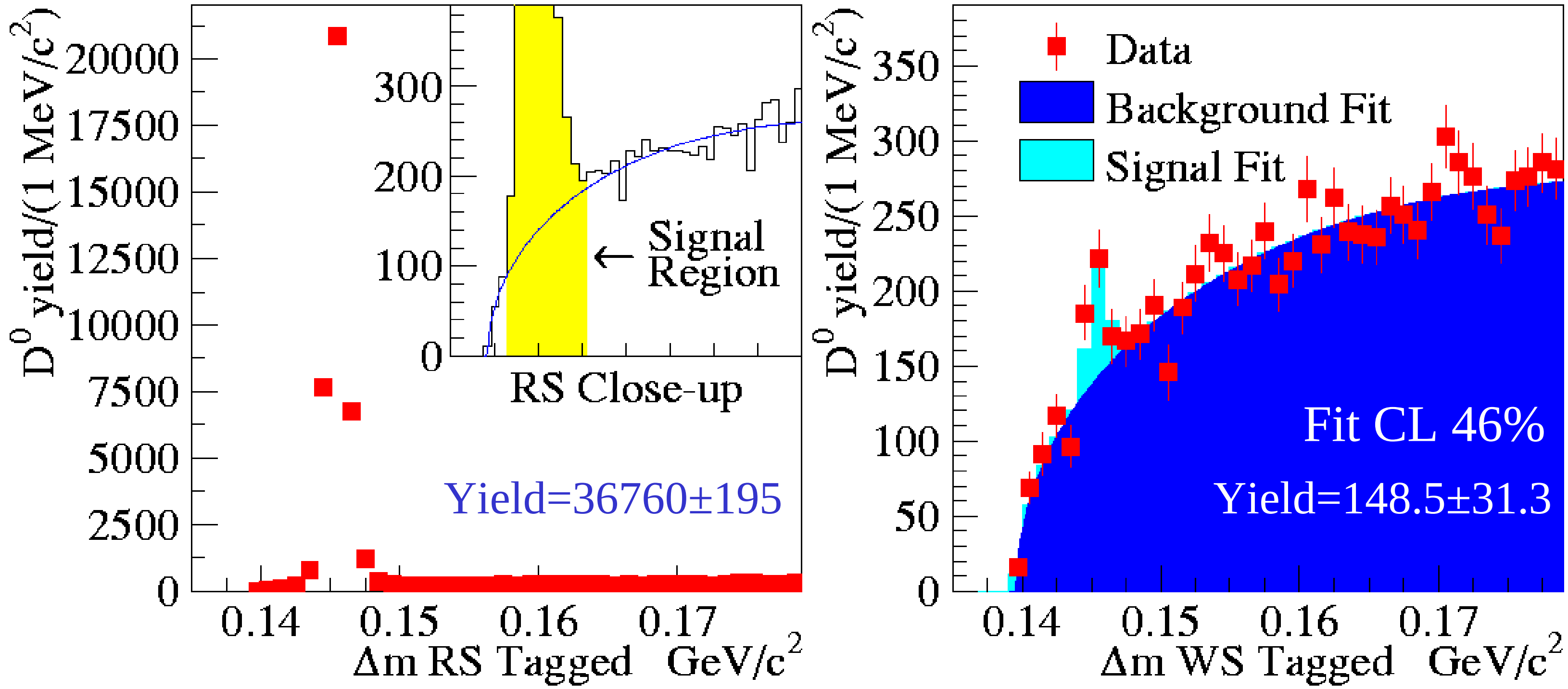
- Fit BG to a polynomial.
- Fit D^0 to a Gaussian.



A total of 80 $K\pi$ fits!

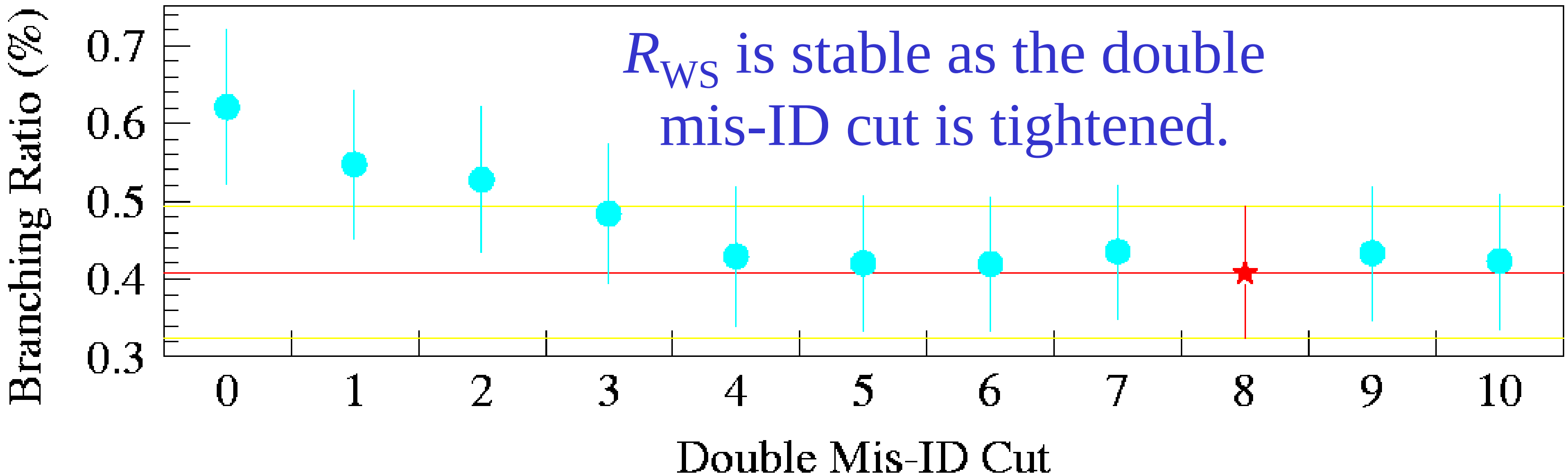
Fit the Mass Difference Distributions

- Fitted D^0 yields are plotted in the appropriate mass difference bins.
- Background is fit to: $f(\Delta m) = a(\Delta m - m_\pi)^{1/2} + b(\Delta m - m_\pi)^{3/2}$.
- WS signal is fit directly to the RS histogram signal region.

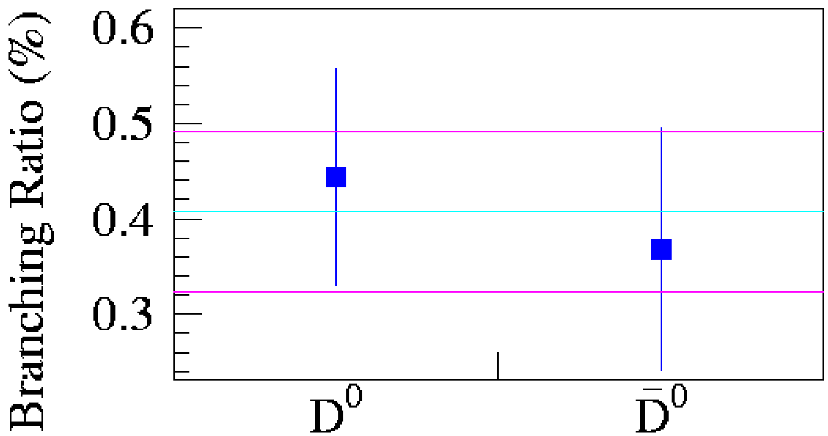


$$R_{WS} = (0.404 \pm 0.085)\%$$

Systematic Studies



R_{WS} is stable as the double mis-ID cut is tightened.



We tested for sensitivity to possible CP asymmetry.

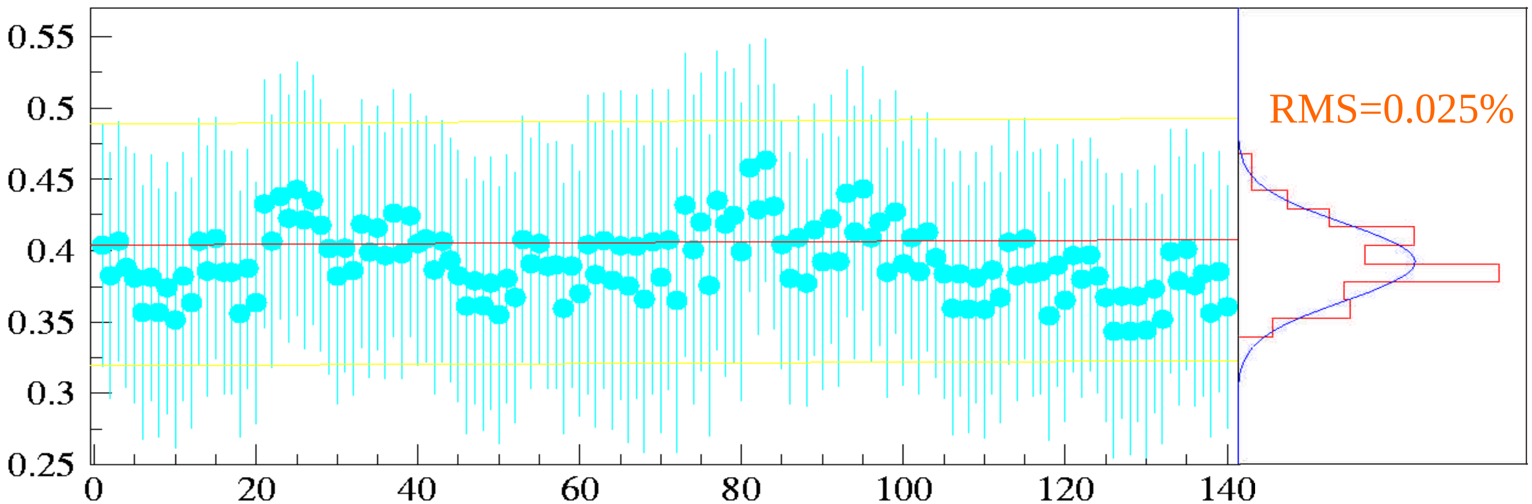
No significant effect.

Systematic Studies

To estimate the systematic error we study several variations

- Different background fit function
- Vary particle ID cut levels.
- Different mass difference binning.
- Shift Monte Carlo reflection distributions.
- Etc.

Each different measurement is treated as equally likely and we take the RMS of the distribution to be the systematic error.



$$R_{WS} = (0.404 \pm 0.085 \pm 0.025)\%$$

Effects of Mixing on R_{WS}

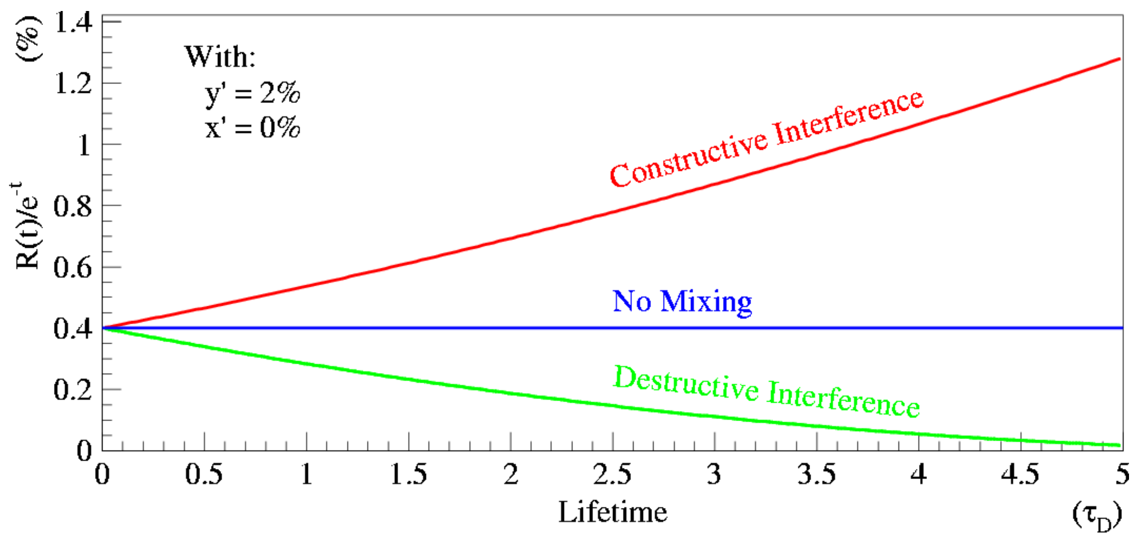
If charm mixing is significant the WS decay rate as a function of time is

$$R(t) = e^{-t}\left(R_{DCS} + \sqrt{R_{DCS}}\, y' t + \frac{x'^2 + y'^2}{4} t^2 \right)$$

With $\quad x' \equiv x \cos d + y \sin d, \quad y' \equiv y \cos d - x \sin d,$

$$x \equiv \frac{\Delta m}{\Gamma}, \quad y \equiv \frac{\Delta\Gamma}{2\Gamma}$$ and δ is the relative strong phase.

The measured branching ratio depends on the lifetime acceptance of the analysis.



Effects of Mixing (Continued)

We use a large RS Monte Carlo to study the effects of mixing on R_{WS}

$$\left(D^0 \to K^+ \mathrm{p}^-\right)_{data}^{expected} = \sum_i^{MC\ accepted} W\left(t_i, x', y', R_{\mathrm{DCS}}\right)$$

Where

$$W\left(t, x', y', R_{\mathrm{DCS}}\right) = \frac{N_{data}}{N_{MC}}\left(R_{\mathrm{DCS}} + \sqrt{R_{\mathrm{DCS}}}\, y' t + \frac{x'^2 + y'^2}{4} t^2\right)$$

Summing and solving for R_{DCS} we find…

$$R_{\mathrm{DCS}} = y'^2 \langle t \rangle^2 - \frac{\left(x'^2 + y'^2\right)}{4}\langle t^2 \rangle + R_{\mathrm{WS}} - \frac{y'}{2}\langle t \rangle \sqrt{y'^2 \langle t \rangle^2 - \left(x'^2 + y'^2\right)\langle t^2 \rangle + 4R_{\mathrm{WS}}}$$

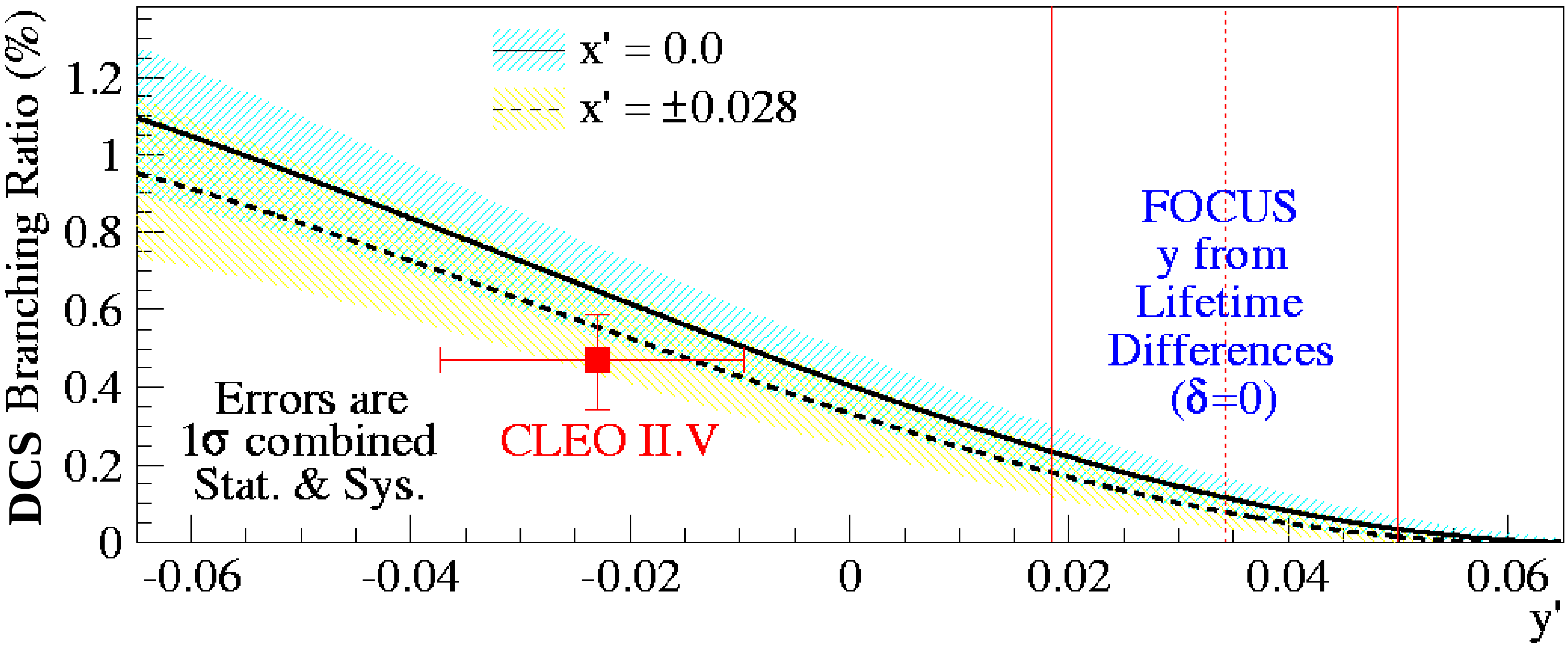
Where $<t>$ and $<t^2>$ are in units of the D^0 lifetime.

From the Monte Carlo:

$$\langle t \rangle = 1.578 \pm 0.008 \quad \text{and} \quad \langle t^2 \rangle = 3.61 \pm 0.03$$

R_{DCS} Dependence on y'

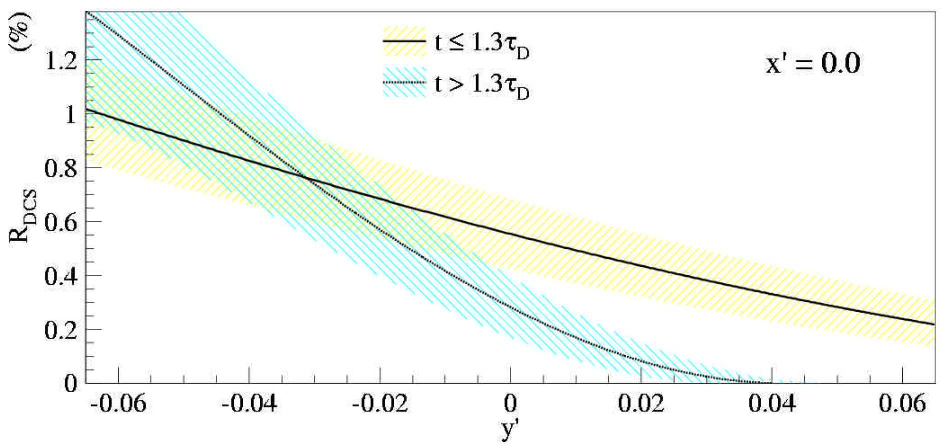
and comparison to other mixing measurements



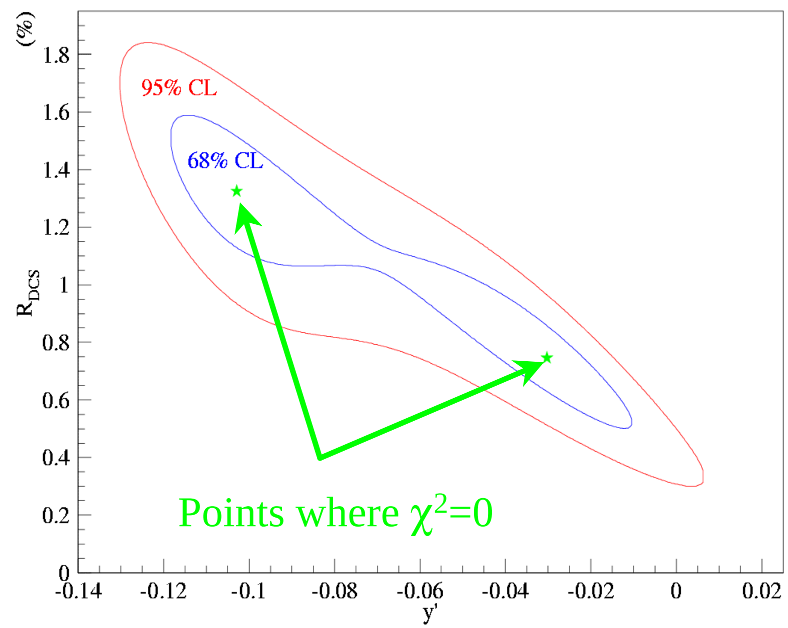
The FOCUS *y* measurement is only directly comparable to the *y´* measurements if the strong phase δ is zero!

Method for Measuring y' (Preliminary!)

Split the data into long and short lifetime samples.



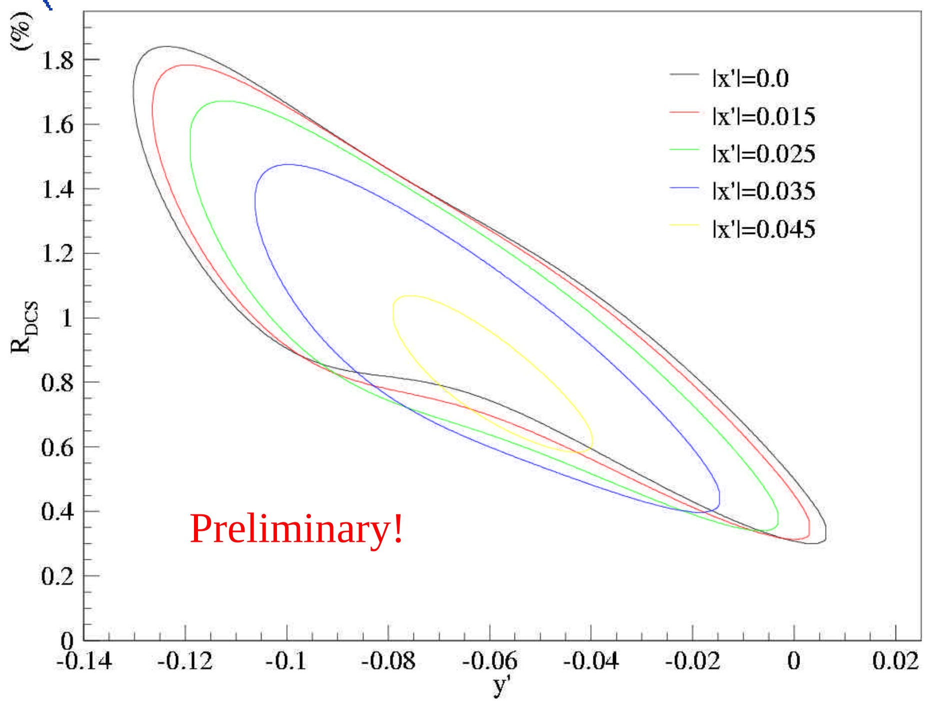
This suggests a negative value of y' (as seen by CLEO).

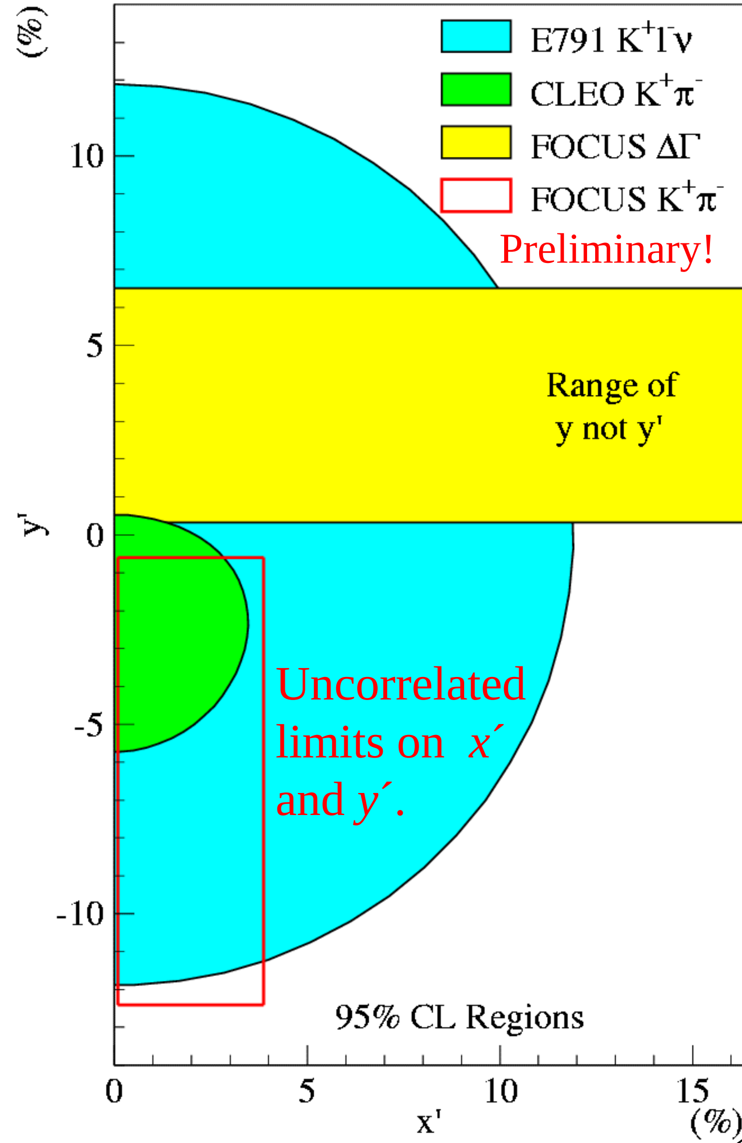


We get the following Bayesian limits at 95% CL (with x'=0):

$$-0.124 < y' < -0.006 \quad \text{and} \quad 0.43\% < R_{DCS} < 1.73\%$$

We can also put a limit on x'





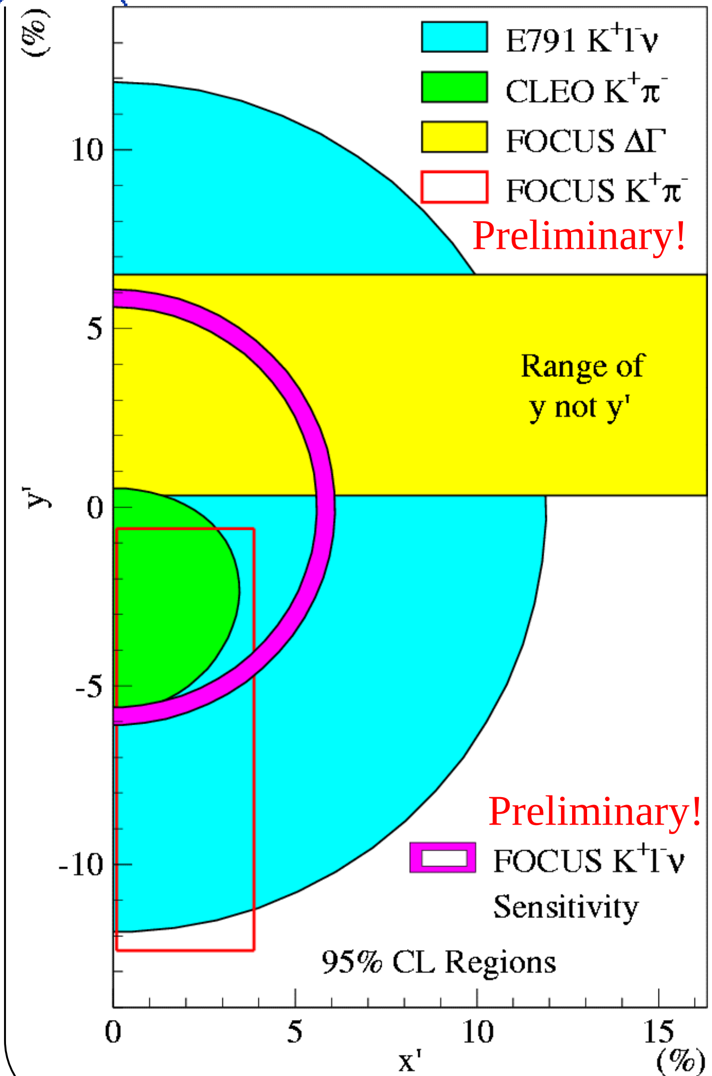
By integrating the likelihood over all allowed values of y' and R_{DCS},

we obtain the limit

$$|x'| < 0.039$$

at the 95% CL.

Future Mixing Studies in FOCUS



- Semileptonic Wrong Sign Decays.

  No DCS backgrounds, but no interference enhancement. Expect R_{mix} sensitivity around 1.6×10^{-3}.

- Full Lifetime Analysis on DCS Decays.

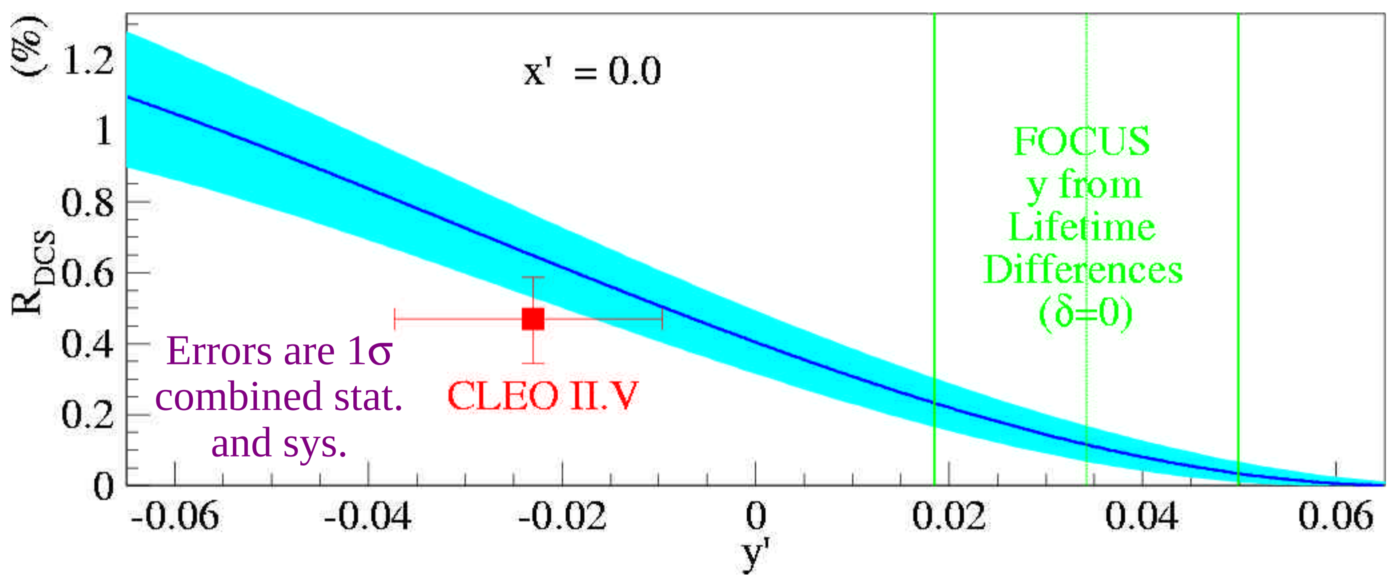
  Better statistics and lifetime resolution than CLEO, but worse S/N. Include more modes like $K\pi\pi^0$ and $K3\pi$.

- Lifetime Difference with CP odd States.

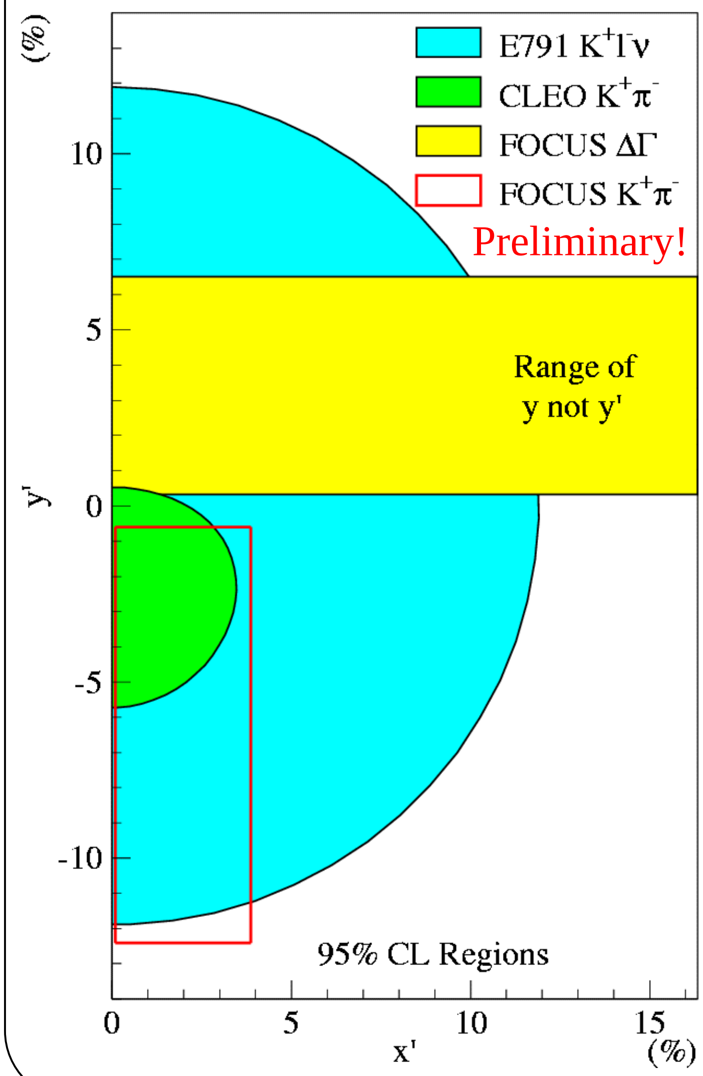
  Involve decays that interfere with CP even states on the Dalitz surface. Experimentally difficult (K_S and π^0) and rare processes.

Conclusions

- Direct measurement of y=(3.42±1.39±0.74)% from lifetime differences.
- New measurement of the branching ratio D^0 g $K^+\pi^-$ normalized to D^0? $K^-\pi^+$ (R_{WS}). In the limit of no mixing this is just R_{DCS}=(0.404 ± 0.085 ± 0.025)%
- Placed this measurement in a physically meaningful context for the case of significant charm mixing:



Conclusions (continued)



- Used this measurement to study limits on x', y' and R_{DCS}.
- The limits are consistent with the negative leaning y' from CLEO II.V.

The FOCUS and CLEO mixing measurements suggest two scenarios:

1. There is *y*-like mixing of a few % and a large strong phase δ.
2. The recent mixing measurements are fluctuations and there is no mixing at the % level.